LANSCE
Los Alamos Neutron Science Center

Research Proposal for the use of Neutron Science Facilities

☐ Fast Access ☐ Joint CINT Proposal

Proposal Number: 20111538
Submission Number: S1571
Date Received: 03/09/11

Program Advisory Subcommittee: Basic Nuclear/Particle Physics
Focus Area:

Flight Path/Instrument: 1FP14 / DANCE
Estimated Beam Time (days): 5
Days Recommended: 0
Dates Desired:
Impossible Dates:

TITLE
Measurement of neutron-capture cross sections on 87Sr and deexcitation gamma rays in 88Sr relevant to the nuclear astrophysics

☒ Continuation of Proposal #: 20101550
☐ Ph.D Thesis for:

Principal Investigator: Rusev, Gencho
Institution: Duke University (TUNL)
Citizenship: Bulgaria
Phone: (919) 660 2636 **FAX:** (919) 660 2634
Email: rusev@tunl.duke.edu
Local Contact: Ullmann, John L.

Co-Proposers	Institution	Citizenship	E-mail Address
Baramsai, Bayarbadrak	North Carolina State University	Mongolia	bayar@lanl.gov
Bredeweg, Todd A	Los Alamos National Laboratory	United States of Am	toddb@lanl.gov
Chyzh, Andrii	Lawrence Livermore National Lab	Ukraine	chyzh1@llnl.gov
Couture, Aaron	Los Alamos National Laboratory	United States of Am	acouture@lanl.gov
Jandel, Marian	Los Alamos National Laboratory	Slovak Republic	mjandel@lanl.gov
Kelley, John H.	North Carolina State University	United States of Am	kelley@tunl.duke.edu
Kwan, Elaine	Lawrence Livermore National Lab	United States of Am	kwan12@llnl.gov
Mitchell, Gary E.	North Carolina State University	United States of Am	mitchell@tunl.duke.edu

RESEARCH AREA

☐ Biological and Life Science
☐ Chemistry
☐ National Security
☐ Earth Sciences
☐ Engineering
☐ Environmental Sciences
☒ Nuc. Physics/chemistry
☒ Astrophysics
☐ Few Body Physics
☐ Fund. Physics
☐ Elec. Device Testing
☐ Dosimetry/Med/Bio
☐ Earth/Space Sciences
☐ Materials Properties/Test
☐ Other:

☐ Mat'l Science (incl Cond Matter)
☐ Medical Applications
☐ Nuclear Physics
☐ Polymers
☐ Physics (Excl Condensed Matter)
☐ Instrument Development
☐ Neutron Physics
☐ Fission
☐ Reactions
☒ Spectroscopy
☐ Nuc. Accel. Reactor Eng.
☐ Def. Science/Weapons Physics
☐ Radiography
☐ Threat Reduction/Homeland Sec.
☐ Other:

FUNDING AGENCY

☐ DOE/BES
☐ DOE/OBER
☒ DOE/NNSA
☐ DOE/NE
☐ DOE/SC
☐ DOE/Other

☐ DOD
☐ NSF
☐ Industry
☐ NASA
☐ NIH
☐ Foreign:

☐ Other US Gov't:
☐ Other:

PUBLICATIONS

Publications:

NONE

Abstract: S1571_proposal-87S.pdf

By electronic submission, the Principal Investigator certifies that this information is correct to the best of their knowledge.

Safety and Feasibility Review*(to be completed by LANSCE Instrument Scientist/Responsible)*

☐ **No further safety review required** ☐ **To be reviewed by Experiment Safety Committee**

☐ **Approved by Experiment Safety Committee,Date:**

Recommended # of days:	**Change PAC Subcommittee and/or Focus Area to:**	**Change Instrument to:**

Comments for PAC to consider:

Instrument scientist signature: **Date:**

Measurement of neutron-capture cross sections on ^{87}Sr and deexcitation gamma rays in ^{88}Sr relevant to the nuclear astrophysics

R. Raut, G. Rusev[1], A. P. Tonchev, W. Tornow
Duke University and Triangle Universities Nuclear Laboratory

J. H. Kelley, G. Mitchell
North Carolina State University and Triangle Universities Nuclear Laboratory

B. Baramsai, T. Bredeweg, A. Couture, M. Jandel, J. O'Donnell, R. Rundberg, J. L. Ullmann
Los Alamos National Laboratory

A. Chyzh, E. Kwan
Lawrence Livermore National Laboratory

Abstract

The investigation of the photoabsorption cross section, σ_γ, below the neutron-separation energy S_n and the related dipole-strength function is important for nuclear structure as well as for nuclear astrophysics. It is a long standing question of nuclear physics to specify the extension of the $E1$ strength to energies far below the maximum of the Giant Dipole Resonance. A variety of experiments have been performed to determine the dipole-strength function below S_n, e.g. measurements of (n, γ) reactions at isolated neutron resonances, $(n, n'\gamma)$, $(p, p'\gamma)$, (^{3}He,^{3}He$'\gamma$), (^{3}He,$\alpha'\gamma$) and (γ, γ') reactions. Although the (γ, xn) cross sections were measured extensively several decades ago for almost all stable nuclei, there are scarce photon-scattering experiments which provide information for σ_γ. The determination of σ_γ relies on Monte Carlo simulations of γ-ray cascades in order to estimate the intensity of the branching transitions from excited levels and the related branching ratios for ground-state transitions. Since the analysis of the (γ, γ') experiments depends strongly on the results of the γ-ray cascade simulations, a stringent test of the simulations is mandatory. A test of the model strength function used in the analysis of ^{88}Sr(γ, γ') experiment can be performed using the DANCE calorimeter by measuring the neutron-capture γ rays from ^{87}Sr. Furthermore, investigation of the chronometric pair ^{87}Rb-^{87}Sr is of special interest to astrophysics, which requires the neutron-capture cross section on ^{87}Sr to be known with accurate precision. These data are also needed for the determination of the neutron density during the s process.

We propose an prolongation of our neutron-capture experiment on ^{87}Sr at LANSCE using the DANCE calorimeter which we carried out in 2010. We intend to use the same self supporting target of 93% enriched ^{87}Sr of thickness 50 mg/cm^2. We are requesting 120 hours of beam time in order to collect enough statistics in the γ-ray spectra from the weak neutron resonances.

[1]Corresponding Author: rusev@tunl.duke.edu

1 Motivation

In the astrophysical models for supernovae explosion, nuclei are exposed in strong photon fluxes with thermal distributions. New nuclides can be produced by photodisintegration from previously formed heavier isotopes assuming the possibility for multi-step excitations of the nucleus by low-energy photons, i.e. a photon can be absorbed from an excited state before it decays leading to subsequent increase in the excitation energy and thus attaining the particle emission threshold. Moreover, the emission of photons, which is related to the photoabsorption cross section σ_γ, by an excited nucleus determines the stellar temperature and hence the photon flux in the interior of the star. It was demonstrated in astrophysical network calculations [1] that different assumptions of the dipole strength below the neutron-separation energy, especially structures such as pygmy resonances superimposed on the tail of the giant dipole resonance, lead to large discrepancies in the abundances of the isotopes. Therefore, precise knowledge of σ_γ and the γ-ray strength function at energies below the particle-emission threshold is of importance for a better modelling of astrophysical processes such as the p process.
Direct measurement of the absorption of photons from a target enriched in a given isotope becomes extremely difficult because of the competing process of atomic scattering, especially for high Z targets. Therefore such photoabsorption measurements were performed only for a few light nuclei. Further, the photon-scattering experiments lead to complicated deexcitations patterns, involving, in many cases, very weak transitions which form a continuum in the measured γ-ray spectra. The determination of σ_γ requires identification of all transitions deexciting a given level, populated by absorption of a photon, in order to estimate the branching ratio B_0 for the ground-state transition. Direct determination of B_0 from the measured spectrum becomes impossible at excitation energies above 4-5 MeV, where every individual branching transition carries only a very small intensity which is below the detection sensitivity. This problem can be resolved by means of γ-ray cascade simulations, see e.g. Refs. [2, 3]. The cascade simulations can provide an estimate of a spectrum of γ-rays depopulating levels at a given excitation energy and the B_0 ratio. The consistency between the input strength function to the γ-ray cascade simulations and the obtained photoabsorption cross section from the analysis of photon-scattering experiment is the only criterion used for validation of the simulations. A test of the model strength function [4] using a different reaction such as (n, γ) becomes very important.
The ^{87}Sr$(n, \gamma)^{88}$Sr reaction is an interesting case for a measurement using the DANCE calorimeter because of the specific structure of ^{88}Sr. Recent photon-scattering experiments on $N = 50$ nuclei [2, 5, 6] reported pygmy resonances at excitation energies around 9 MeV with strength about 2% of the $E1$ energy-weighted sum rule. Originally, $E1$ pygmy resonances were observed in neutron-capture experiments (see, e.g., the review in Ref. [7]). It is therefore necessary to examine the results for the strength function in ^{88}Sr at LANSCE by the ^{87}Sr(n, γ) reaction.
In addition, there are two applications of the neutron-capture cross sections in ^{87}Sr [8] significant to the astrophysics: (i) a possible branch in the s process which produce ^{85}Kr can be used as a measure of the neutron density during the s process and (ii) a possible use of the ^{87}Rb-^{87}Sr chronometric pair to measure the age of the Galaxy. If the neutron density during the s process is low, ^{85}Kr ($\tau_{1/2}$ = 10.7 a) will decay before neutron capture and the path of the s-process flow will proceed thorough ^{85}Rb, ^{86}Sr and ^{87}Sr. If the neutron density is high, the flow will produce ^{86}Kr and ^{87}Rb. A comparison of the value of the product σN of the neutron-capture cross section in ^{87}Sr and its abundance with the corresponding value for ^{88}Sr will allow the determination of the branching in the s process and thus the neutron density (see for more

detail Ref. [8]). Therefore, more precise data for the neutron-capture cross section in ^{87}Sr are necessary. More accurate data for the ^{87}Sr(n,γ) reaction and the pure s process abundance of ^{87}Sr are required in order for the pair of ^{87}Rb-^{87}Sr to be useful as a Galaxy chronometer.

2 Experiment

We propose to perform an experiment on ^{87}Sr using the DANCE calorimeter located in FP 14 at the Lujan Neutron Scattering Center at Los Alamos National Laboratory. Neutrons with energies from eV to a few hundreds of MeV are produced by spallation reactions of pulsed 800 MeV proton beams incident on a small tungsten target. The neutron-capture γ rays are measured with the DANCE calorimeter consisting of 160 BaF_2 detectors forming a ball covering a solid angle of almost 4π. The calorimeter has an efficiency of 86% for a single γ ray and resolution of about 14%. DANCE also allows measurement of the time of flight of the neutrons from the spallation target to the experimental target and thus determination of the energy of the captured neutron. In this particular proposal, we are interested of incident neutrons with energies up to 50 keV. The high segmentation and high efficiency of the BaF_2 array allows the measurement of the cascade γ rays following neutron capture. Gamma-ray spectra from ^{88}Sr will be collected for different multiplicities, needed for spin assignment for the neutron resonances and more stringent test of the γ-ray strength-function models. The Q value of the ^{87}Sr(n,γ) is 11.1 MeV, which gives the advantage of removing all background γ rays result from neutron capture in the BaF_2 detectors or ^{86}Sr and ^{88}Sr contaminating the target.
We aim to take full advantage of the DANCE calorimeter collecting γ-ray spectra with applied cuts on the Q value of the ^{87}Sr(n,γ) reaction, the individual neutron resonances and the desired multiplicity.

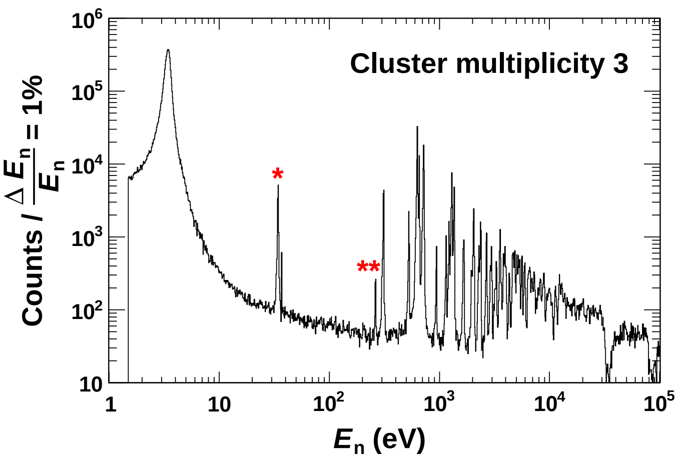

Figure 1. A time-of-flight spectrum collected from the ^{87}Sr(n,γ) experiment carried out in 2010. The spectrum is produced with cuts applied on the total γ-ray energy from 10 to 12 MeV and on the cluster multiplicity equalled to 3. Measured γ-ray transitions deexciting the resonances labelled with "" and "**" are shown in Fig. 2.*

We carried out the ^{87}Sr(n,γ) experiment in 2010 at the DANCE calorimeter for about 130 hours beam-on-target. The time-of-flight and the γ-ray spectra from the aforesaid measurements are shown in Figs. 1 and 2. However, the short measuring time lead to a small statistics in the spectra from weak resonances (cf. left panel in Fig. 2) which cannot provide conclusive results for the spin assignment of those resonances. Therefore, we would like to extend the measurement with the ^{87}Sr(n,γ) for another 120 hours. In addition, due to the low level density in ^{88}Sr, the transitions between the low-lying states are clearly visible in the measured γ-ray spectra. Having higher statistics, will allow further analysis of the feeding transitions to the low-lying levels by building $\gamma\gamma$- or $\gamma\gamma\gamma$-coincidence matrices and study the two-step cascades to an excited level.

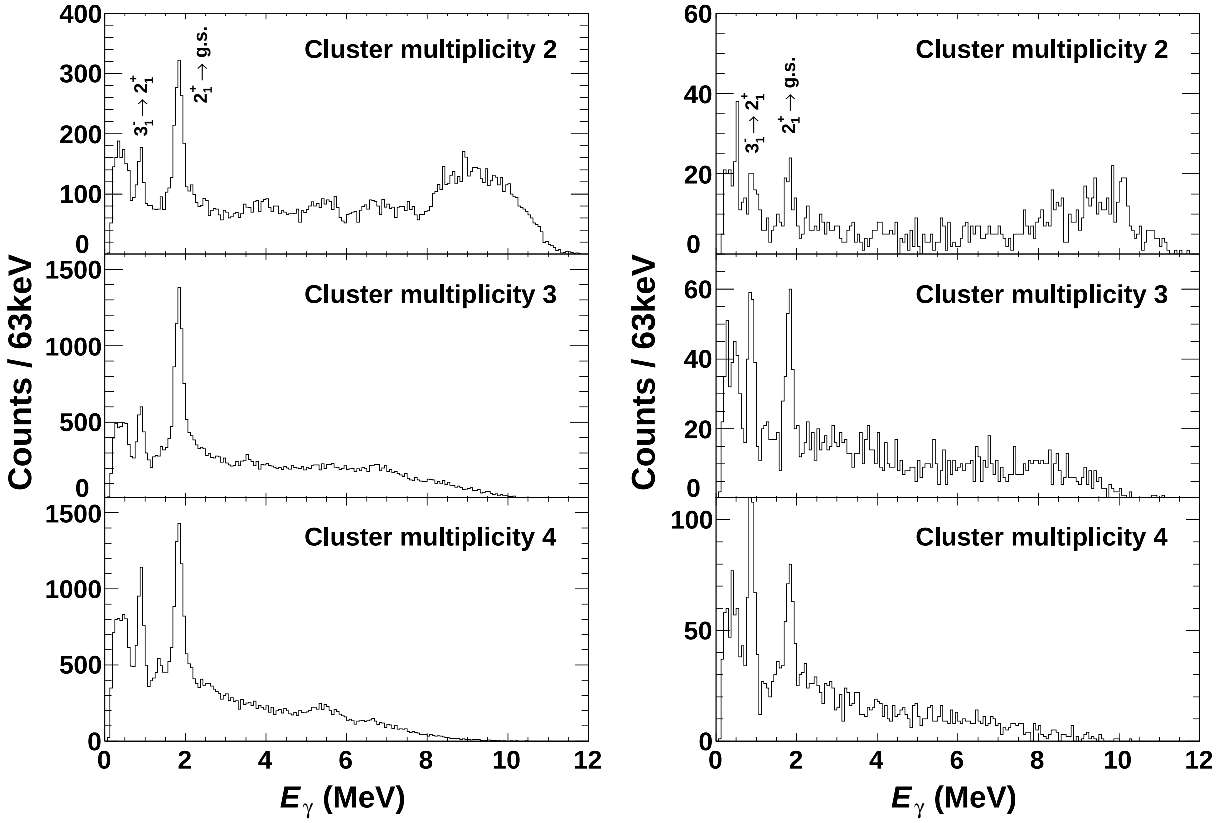

Figure 2. Measured γ-ray spectra from ^{88}Sr in coincidence with the neutron resonances labelled with "" (left panel) and "**" (right panel) in Fig. 1 and applied cut on the total γ-ray energy from 10 to 12 MeV. The spectra are shown for different cluster multiplicities.*

3 Beam-time request

Flight path 14 provides neutron flux with energy dependence described approximately by $\Phi_n = B/E$, where $B = 1.4 \times 10^4$ s^{-1}cm^{-2}. Based on our previous experiment at DANCE using 50 mg/cm^2 ^{87}Sr target, we expect 450 counts/2.5 keV in the neutron time-of-flight spectrum. We intend to use the same self-supporting target of 93% enriched ^{87}Sr available at LANSCE. According to the goal of the extension of the ^{87}Sr$(n,\gamma)^{88}$Sr experiment, to double the statistics of the acquired data, we request five days (120 h) of beam time.

4 Summary

In summary, we propose an extension of the experiment on ^{87}Sr(n,γ) reaction at neutron energies up to 50 keV measuring the neutron-capture γ rays with the DANCE calorimeter. Our goal, to double the statistics of the acquired data, is motivated by (i) the spin assignment for weak resonances and (ii) the opportunity to built $\gamma\gamma$ coincidence matrices and to study the two-step cascades ending at the low-lying states in ^{88}Sr. The results from the proposed experiment will serve as a stringent test for the determined γ-ray strength function for ^{88}Sr from previous photon-scattering experiment [2]. In particular interest is the validation of the observed pygmy resonance. The proposed experiment will provide more accurate results for the widths and energies of the neutron-capture resonances in ^{88}Sr, which are also of nuclear astrophysics interest for determining the nuclear density during the *s* process and as a Galaxy chronometer.

References

[1] S. Goriely, Phys. Lett. B **436**, 10 (1998).

[2] R. Schwengner, G. Rusev, N. Benouaret *et al.*, Phys. Rev. C **76**, 034321 (2007).

[3] G. Rusev, R. Schwengner, F. Dönau *et al.*, Phys. Rev. C **77**, 064321 (2008).

[4] A. R. Junghans, G. Rusev, R. Schwengner *et al.*, Phys. Lett. **B 670**, 200 (2008).

[5] R. Schwengner, G. Rusev, N. Tsoneva *et al.*, Phys. Rev. C **78**, 064314 (2008).

[6] N. Benouaret, R. Schwengner, G. Rusev *et al.*, Phys. Rev. C **79**, 014303 (2009).

[7] G. A. Bartholomew, E. D. Earle, A. J. Ferguson *et al.*, Adv. Nucl. Phys **7**, 229 (1972).

[8] R. W. Bauer, G. Bazan, J. A. Backer *et al.*, Phys. Rev. C **43**, 2004 (1991).